IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received March 20, 2018, accepted April 19, 2018, date of publication June 7, 2018, date of current version June 20, 2018.

*Digital Object Identifier 10.1109/ACCESS.2018.2833551*

# Towards Energy Saving in Computational Clouds: Taxonomy, Review, and Open Challenges

**QAISAR SHAHEEN[1], MUHAMMAD SHIRAZ[2], SULEMAN KHAN[3], RABIA MAJEED[4], MOHSEN GUIZANI[5], (Fellow, IEEE), NAWSHER KHAN[6,7], AND ALI M. ASEERE[6]**

[1]Department of Computer Science, Superior University, Lahore, Pakistan
[2]Department of Computer Science, Federal Urdu University of Arts, Science and Technology, Karachi 44000, Pakistan
[3]School of Information Technology, Monash University Malaysia, Subang Jaya 47500, Malaysia
[4]Department of Computer Science, COMSATS Institute of Information Technology, Islamabad 45550, Pakistan
[5]Department of Electrical and Computer Engineering, University of Idaho, Moscow, ID 83844, USA
[6]College of Computer Science, King Khalid University, Abha 61421, Saudi Arabia
[7]Department of Computer Science, Abdul Wali Khan University Mardan, Mardan 23200, Pakistan

Corresponding authors: Qaisar Shaheen (qaisar.shaheen2002@gmail.com) and Suleman Khan (suleman.khan@monash.edu)

**ABSTRACT** Cloud Computing involves utilization of centralized computing resources and services, including remote servers, storage, programs, and usages which minimize the power utilization of the client assets. Therefore, it is extremely important to accomplish energy efficiency of cloud computing. Virtualization is used to set up a foundation for the execution part as the heart of energy effective cloud. Virtualization incorporates certain advancements, such as consolidation and resource utilization. A number of techniques, such as DVFS virtualization as well as teleportation can be used by empowering the tasks of multiple virtual types of equipment to a single server to increase the vitality proficiency of datacenters. The objective of this review is to analyze contemporary for energy as well as performance management, vitality for effective data centers and resource distributions. Our review will address the latest issues researchers have addressed in energy as well as management of performance in recent years. We will take a closer look at these existing techniques based on tools, OS, virtualization, and datacenter stages taxonomy. Finally, a performance comparison of existing techniques is presented that can assist in identifying gaps for future research in this area.

**INDEX TERMS** Energy effecticient techniques, scheduling, cloud computing.

## I. INTRODUCTION

The computational cloud consists of interconnected virtual machines and servers, which constructs a data center. This cloud is interrelated to clients through any Internet connection [1], [2]. Project scheduling has a major use of cloud computing. On the other hand, task scheduling provides a mapping of components to a suitable choice of assets and its implementations [3]. The amount of these jobs can be large and can continue arriving in a specific way. Scheduling systems are being used to give compelling task handling by increasing the speed of a process and amplifying asset consumptions [4]. Scheduling on the cloud has many characteristics: Task scheduling in which every pivot in the cloud remains unrestricted. The purpose of scheduling in a cloud setting is manifold: assign ideal tasks to clients' scheduling [5]; pass on the cloud framework throughput and attain high load adjusting levels; pass on the full nature of the administration and meet the economic guidelines [1].

Shahzad *et al.* [6] discussed countless vitality efficient scheduling algorithms. Some of those algorithms remain centered on vigorous power, frequency scaling as well as other on machine virtualization [7]. In order to minimize the energy utilization of the processor, DVFS empowers them to execute at a distinctive blend of frequency and voltage [8], [9]. Host virtualization can be used to enable certain applications of cloud computing. Even though the levels of energy utilization are unidentified in host virtualization [10], it is influenced by the allocation of computing properties, abundant accessibility, as well as utilization of hardware speculations.

While in machine virtualization [11], every device has numerous simulated devices as a result of which the applications are executed in a cloud environment. Better source use and proficient energy putting something aside on behalf of resource utilizing relocation of simulated devices and relocation of slog burden in workload consolidation [12]. By the fluctuating requirements and available resources suggestions, simulated devices can be swapped above the hosts. The virtual machine repositioning method focuses on placing virtual machines in such a path [13], to the point that the power increment is low. The best energy proficient centers are selected and the virtual machines are swapped transverse above of them [14]. The movement intimates more adaptable asset administration as virtual machines can move starting with one host then onto the next. It uproots the knowledge of the area in virtualized situations [15]. The primary function of a modern computing system in architecture is to break the control as well as vitality expenditure.

We have reviewed latest techniques in energy as well as management of performance. Then, we proposed the categorization of existing techniques based on tools, OS, virtualization, and datacenter stages taxonomy. Finally, a performance comparison of existing techniques is presented.

The remainder of this paper is organized as follows. Section II explains the suggested arrangement for the classification of current energy efficiency methods and algorithms and reviews current techniques based on the proposed taxonomy. Section III presents a study of vitality efficiency techniques in cloud computing on the basis of performance and energy savings. In Section IV, we present the conclusion and draws forthcoming research directions.

## II. TAXONOMY OF ENERGY/POWER MANAGEMENT TECHNIQUES IN CLOUD COMPUTING

Energy and power techniques are associated with each other in the management of computing systems [16]. High-level power or energy efficient methods are distributed on static and dynamic energy administration as presented in Figure 1. Static energy administration includes entire streamlining procedures that are connected to the planning phase [17]. DPM methods are eminent by the stratum which they have connected either hardware or software, DPM changes to diverse hardware parts [18]. However, generally, it might be delegated as DVS. For example, resource throttling and DVFS, also incomplete or complete dynamic component deactivation (DCD) at times of latency.

### *A. HARDWARE LEVEL*

From an equipment perspective, Static Power Management (SPM) comprises entire advanced techniques which connected on outlined time with track, design, rationale and framework levels. Track level advancements are centered on the sparing of exchanging actions of specific rational doors and semiconductor level combination tracks by the use of a mind-boggling entryway outline and transistor estimation. Improvements at the rational point are gone for the switching action force of rational point integration and successive tracks. As shown in Figure 1, DPM techniques could essentially distribute in binary classifications: Dynamic Component Deactivation (DCD) as well as Dynamic Performance Scaling (DPS) [19]. Low-power states generally prompt included force utilization and intrusions brought on through the reinstatement of the segments. For instance, when trying to minimize energy usage in data centers, Lin *et al.* [20] investigated how much can be saved by dynamically adapt the data center by turning off servers during low periods. They proposed a general model that can help achieve target power savings. On the other hand, real power administration can be transformed to online advancement issues. This can help minimize energy levels and promote, in time of latency, the extension to gather deferral of moves on the dynamic conditions [21].

#### 1) DYNAMIC COMPONENT DEACTIVATION (DCD)

PC parts that do procurement execution scaling and must be incapacitated introduce methods that will influence the capability and impair the segment when it is unmoving. The issue is slightly different when accounting for an immaterial move. In all actuality, such moves may take extra energy extraction. Along these lines, to accomplish productivity a movement must be completed just if the unmoving duration is satisfactorily extended to complete the move on time. In utmost true frameworks, there is a restricted or no learning almost the forthcoming assignment. Thus, an anticipation of a successful movement must be done giving to recorded information or about the framework. A lot of work has been done in creating proficient systems to tackle current energy issues [22]. As illustrated in Figure 1, the recommended DCD methods could distribute keen on foretelling as well as hypothetical. Static methods use some limit for a continuous implementation factor to create forecasts of unmoving phases. The easiest approach is known as an altered break. The thought is to characterize the time span after which a time of idleness dealt with sufficiently extensive to make a move to a minimum energy level. Enactment of the segment started once the initial demand for a part is received [23]. The strategy has two focal points: it can be connected to any sort assignment, and up down forecasts that can be handled by confirming the estimation of the respite limit. Then, inconveniences are self-evident: the arrangement requires change of the edge for every workload, it generally prompts an execution misfortune on the enactment, and the vitality is devoured following the start of an unmoving phase to the respite is squandered. Two approaches to defeat the downsides of the settled respite approach have been suggested: prescient quiets down and prescient takedown.

#### 2) DYNAMIC PERFORMANCE SCALING (DPS)

Dynamic Performance Scaling (DPS) incorporates distinctive systems which could connect towards PC parts associated element change of their execution relatively to the force utilization [24]. Rather than complete deactivations, a few parts, for example, CPU, permit progressive diminishments or increments of the clock recurrence alongside the conformity of the source energy in circumstances at what time the asset is not used for the complete limit. This thought consists of the foundations of the generally received DVFS method [25].

### 3) DYNAMIC VOLTAGE AND FREQUENCY SCALING (DVFS)

Regardless of the fact that the CPU recurrence could balance independently, recurrence ascending without anyone else is in-frequently advantageous as an approach to save exchanging forces. Sparing the most power requires dynamic voltage scaling as well, as a result of the V2 part and the way that present-day CPUs are unequivocally upgraded for low voltage states [26]. DVFS decreases many directions a CPU can dispute in a specified measure phase, hence diminishing the execution. Thus, building executions for system sections that are adequately CPU-bound. This creates difficulties of giving ideal vitality and execution control [27].

These have attracted researchers' attention in the last few years. We will examine the literature and explore the accompanying areas. A progressing cloud framework where each steady organization solicitation is displayed as RT-VM in resource delegates was proposed in [28]. Accordingly, we inspect the provisioning of virtual machines for ongoing cloud administrations. A reenactment results exhibit that data-centers could decrease power utilization and construct their advantage by using DVS arrangements [29]. The proposed adaptable arrangements, adaptive DVS and progressive DVS, illustrate further the advantages with minimum energy use irrespective of the framework substance [30]. Also, the implementation phase of a project using a processor might not be contrarily relative to the regulator recurrence, and DVFS may bring about nonlinearity in the execution time [31]. The relationship between framework parts and force use of the a distributed computation setting contemplate and analyze the coordination of errand sorts and portion power similarity frameworks [32]. After that, they show an asset booking calculation of Cloud Computing concentrated around vitality productive upgrade routines. The exploratory results uncover that for occupations that are not completely won by the equipment environment, utilizing their calculation can altogether cut vitality utilization [33]. A lining theoretic model, which predicts the ideal force conveyance much of the time is introduced in [34]. Results are checked by a method for investigations on an IBM Blade focus. They investigate that the perfect force assignment varies for various circumstances. It is not for the most part perfect for running servers at their most amazing force stages. There are circumstances that it could be perfect to execute servers at most negligible force stages or at about most of the way power levels. Their examination shows that the perfect force dispersion is non-clear and relies on upon various parts, for instance, the force of recurrence relationship in the processors, a passage rate of undertakings; most noteworthy server recurrence, most diminished achievable server recurrence and server focus game plan.

The major test of utilizing renewable energies is the variable, unpredictable and flighty nature depicted in [29]. By showing an experimental classification of the latest research and exploring new challenges in managing the proper use. They answer why, when, where and how to power, renewable vitality in server farms. Especially, they acknowledge that coordinating vague force interest and multi-sourced supply should be the highlights of future investigation. However, the implementation of DVFS could appear to be development, actual classifications raise various complications which should be well thought-out. Initially, because of compound (multi-faceted) designs of present processors, the approximations of the mandatory processor clock rate of recurrence that will come across application requirements are not inconsequential. One more issue is that apart from the concept, energy intake by a CPU may not be meeting its resource energy requirements. For instance, some framework can comprise a number of resource dynamisms that influence contradictory chunks of the chip. Furthermore, the implementation phase of the program in a row scheduled the CPU could not contrariwise proportionate to the regulator rate of recurrence. DVFS might outcome smart multidimensional by the implementation time. Also, reducing the CPU might take some deviations in orders in which jobs are programmed. In the abstract, DVFS can offer significant power utilization; though, this must functional sagaciously, by way of outcome could considerably differ aimed at HW and SW system frameworks. Methodologies which put on DVFS towards minimizing power utilization by the system can be distributed into interlude centered, inter-job and intra job [8]. Interlude centered processes remain alike to susceptible foretelling DCD methodologies now as well as to consume data of the earlier phases consist of CPU events.

## B. OPERATING SYSTEM LEVEL

In this area, examination meets expectations. That is the arrangement with the force effective asset administration at the working framework level has been discussed. The attributes cast-off to group the mechanism is displayed in Figure 1. To focus the best critical attributes of the mechanisms, are summarized in Table 1.

## C. VIRTUALIZATION LEVEL

This assists the generalization of the OS as well as solicitations administration scheduled on or after the HW. There are two methods for how a VMM can take an interest in the force administration. In restricted, a VMM might go about as an OS deprived of qualification among VMs: screen by and large framework's execution [36] what's more, suitably apply DVFS or any DCD methods to the framework parts. IDC has two sorts of virtualization expertise, those will be considered later. First, there exists a complete VM expertise, for instance, VMWare [15]. Complete VM, also recognized by way of inbuilt virtualization, usage of a VM which arbitrates among the visitor OS as well as built-in HW. VMM enables among visitor OS as well as HW. Convinced privileged directions should be confined and controlled inside the VMM since the main hardware is not maintained by the SW. In addition, para-virtualization is a precise standard method that has about similarities to full virtualization. This procedure of VMM usage aimed at mutual admittance towards original HW,

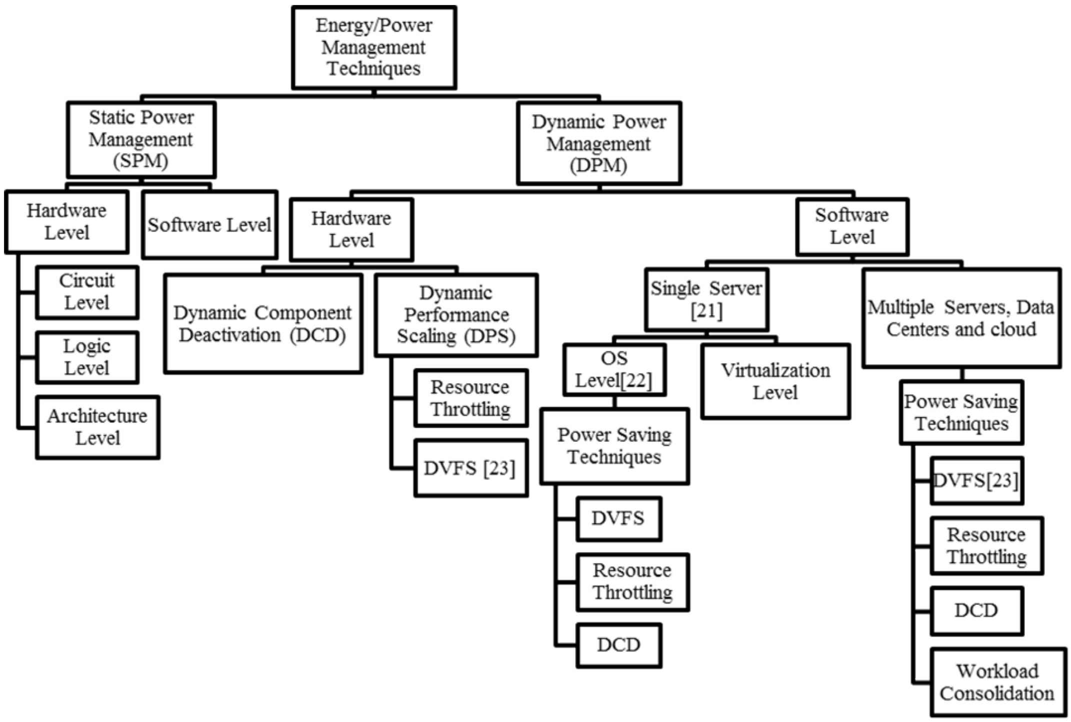



**FIGURE 1.** Taxonomy of energy efficiency techniques in energy/power management.

however, assimilates the VM cognizant program towards OS itself. This method eliminates the requirement for any takes in the OS themselves in order to cooperate in the virtualization procedure. A distinctive para-virtualization artifact is achieved. Though numerous management methods have been established to effectively decrease the server energy usage by switching hardware mechanisms to lower-energy conditions, they cannot be directly pragmatic to present data centers that depend on virtualization tools.

In another route, it is important to influence the OS's particular force administration arrangements and implementation level learning. This is in order to guide energy administration requests as of distinctive VMs on real variations in the equipment's energy phase or authorizes framework inclusive energy restrictions in a composed way [37]. A percentage of the examination work will be explored later. Virtualization utilizes vitality sparing as a part of distributed computing. They suggest that distributed computing with virtualization as an issue to finish the middle wellspring of vitality effectiveness, and the discriminating trade-offs between execution, QoS and vitality productivity [38]. Zhang and Cheng [39] suggested enacloud; an energy efficiency use aware point method for huge scales of cloud stages. An energy responsive exploratory algorithm is suggested to pick a suitable role for dynamic application position. Besides, an over provision methodology is exhibited to manage frequent resource resizing issue [40]. They have carried out their methodology taking into account Xen VMM and their experience proved that it is a sensible answer for recovering the energy for a cloud platform. Powernap, a strategy for killing unmoving power in servers by rapidly transitioning done and finished with an ultra-low power state introduced in [41]. They sit in a prediction of the usefulness of the Power Nap using RAILS with genuine business arrangements. They get their projections using a commercial high thickness server. Science *et al.* [42] presented a force prerequisites, energy transformation efficiency and aggregate power expenditures for three server configurations: an unchanged, current cutting-edge midpoint, for example, the HP c7000: a Powernap-empowered structure using strong, ordinary PSUs (power nap), Power Nap with RAILS [43]. An energy efficiency scheduling methodology and the investigation demonstrate that it can save a lot of time for users, moderate more energy and accomplish a larger amount of load balancing proposed by Li *et al.* [44]. Next, they would test their methodology focused on hardware workloads, e.g. CPU, memory, and assess the viability of the VM relocation so as to moderate more energy [45]. Deng *et al.* [46] made a leading phase in diving keen on the functioning above the renewable energy data center. In [47], they recommended an insubstantial server control administration that takes after renewable power variety attributes, power existing frameworks [48], and applies a supply stack agreeable plan to alleviate the execution overhead. Contrasting and conditioning the workmanship renewable energy driven system plan, the switch could alleviate normal system movement through 75%, top system circulation by 95%, and diminish 80% occupation holding up time even now keeping active 96% renewable energy usage [49].

Parsa *et al.* proposed RASA, making an allowance for the dissemination and versatility qualities of grid resources [50]. The algorithm is assembled through an exhaustive survey and investigation. The task scheduling as the feature to decrease energy consumption has been discussed in [52]. Jobs can be allocated and scheduled using the algorithms. So energy can be preserved.

### D. DATA CENTER LEVEL

The attributes cast-off to characterize the methodologies are exhibited in Figure 1. Typically, a methodology is in view of the combining of the workload crosswise over physical hubs in server farms. The workload can be described by approaching solicitations for virtual administrations, network users, or VMs. The objective is to allow solicitations or VM to the insignificant measure of physical assets and skills or put to rest or snooze expresses the unmoving assets. The issue of the designation is two ways. Initially, it is important to dispense new demands. Second, the execution of existing applications or VMs ought to be persistently observed and if necessary, the portion ought to be adjusted to accomplish the best conceivable vitality proficient exchange off with respect to indicated QoS.

The workload heterogeneity gotten from a genuine cloud environment described in [11]. They have given the initial approach to evaluate the effect of execution impedance on a data centers energy efficiency. Besides, they have introduced an instrument to improve power utilization by misusing the inherent job diversity that occurs in a cloud environment. Outcomes of experiments that demonstrate their suggested component diminishes routinely by 27.5% and builds power utilization up to 15%. Beloglazov [54] proposed and explored a suite of novel systems for executing appropriated element VM merging with IaaS Clouds below the amount of work free QoS requirements [55]. The recommended methodology enhances the usage of data center assets as well as moderates energy intake while fulfilling the characterized QoS prerequisites [56].

## III. PERFORMANCE COMPARISON OF EXISTING ENERGY EFFICIENCY TECHNIQUES IN CLOUD COMPUTING

The substantial number of cloud computing frameworks radiates a lot of carbon dioxide CO2. In addition, it can waste a large amount of energy. A mix of new innovations and courses of action have prompted an unrest in computing is produced and conveyed to end clients. Different methodologies and their strategies exist which adequately help the energy efficiency in distributed computing. Table 1 outlines the most noteworthy qualities of the reviewed research work.

This study comprehensively analyzes and reviews the power proficient techniques in cloud computing. This survey focuses on software-based augmentations that can be simply combined into present substructures and system without considerable modification and autonomous of any site switches. We have also comprehensively studied a few recent surveys that focus on similar topics.

Existing studies in this area have focused on hardware grounded augmentation approaches like energy efficient techniques. The key emphasis of this study is to determine software concerned with power efficient techniques. In this this study, we accomplish that the finest software centered power efficient resolution to reduce energy usage could be achieved through vitality responsive task programming to applicable properties.

This review was conducted by studying the current power responsive source development techniques of cloud computing. The categorization of methods was done to clearly indicate the level of implementation of energy efficient measures within the cloud data centers.

A performance comparison was done to comprehensively represent the implementation of power proficiency procedures of cloud data centers. The vitality efficient procedures reviewed accomplish an anticipated level of the presentation centered on diverse measures. Our prime focus was on energy savings. In cloud computing, virtualization is inherited and it cannot be overlooked. Virtualization provides hardware and software heterogeneity. It also enables the running of multiple operating systems on identical hardware platforms. It leads towards minimizing the number of physical machines.

To date, most of the studies highlight the CPU capabilities to the single unit to achieve energy efficiency. However, a great extent of the computational industry has already adopted the multi-core architecture. This study analyzes the effect of energy efficiency techniques on performance. An optical methodology that efficiently handles the energy with performance as well as economically benefited also, can be developed. An efficient resource allocation technique can be developed that overcome the resource underutilization along with efficient energy usage.

There is a need to design techniques to overcome energy wastage. Usage of dynamic virtual machine migration in a virtualized cloud environment helps to increase performance by equally dividing workload on a different machine at runtime. There is also need for efficient approaches to equally divide the workload.

With the tremendous increase in data-intensive applications, data processing and production have also increased. As a result, it has become a quite complicated task to store a huge volume of data. A noticeable volume of energy is also wasted while handling such large data.

Hence, there is a need for an approach which can overcome the slow processing and storage overhead which may otherwise lead to energy wastage. Although, there is a need to investigate several other areas that can lead to energy efficient cloud computing.

Strategies will articulate to reduce the energy usage, improve resource distribution strategies in forthcoming for sufficient distribution of sources, reduction of the transition overhead, efficient workload distribution, and efficiently manage communications between virtual and physical machines. There are also many open challenges that we list in

**TABLE 1.** Table stylesComparison of energy efficiency techniques in cloud computing.

| References | Techniques | System Resource | Goal | Algorithm | Strength | Weakness | Evaluation Criteria | Energy Savings |
|---|---|---|---|---|---|---|---|---|
| [53] | Consolidation, Server power switching | CPU | Least possible energy consumption | Applications are designed to servers utilizing an exploratory for multi-dimensional storing, bringing about the desired workload dispersion crosswise over servers | Minimal energy allocation of workloads to servers | Slight work on mutual power and performance-aware patterns for multi-dimensional resource distribution | Performance tolerance | 20% |
| [52] | DVFS, geographical distribution of data centers | CPU | Minimize energy consumption, minimize $CO_2$ emissions | Five empirical for scheduling HPC requests over physically dispersed cloud server purpose of reduction of power utilization and carbon outflows, and a boost of the means supplier's benefit | Higher profit and fewer carbon emissions | Compromise resources in multiple locations | Average energy consumption, average carbon emission, profit gained, and workload executed | 25% |
| [57] | DVFS | CPU | Minimize energy consumption, satisfy performance | Energy efficient provisioning of cloud means alongside gathering users QoS prerequisites as characterized in SLAs [58][59]. | Response time and cost saving under dynamic workload scenarios | Efficient service allocation cannot attain | Simulation using CloudSim toolkit | 23% |
| [3] | Task consolidation | CPU, Hard disk | Saving energy possibilities and other operational costs | Task consolidation with unsystematic, ECTC and MaxUtil algorithms are there utilized. Variations of these algorithms were additional performed. | Promising energy saving capability | Resources are not equally distributed | Simulation | 13-18% |
| [26] | DVS | CPU | Power utilization, fulfill enactment requests | DVFS applies for scheduling in real-time VM cloud data center to reduce power usage and limit requirements of applications | Real-time framework | Resources allocated to VM are not specified | Simulation | 15% |
| [60] | Virtual Machine assignment | CPU | Energy efficiency achieved by the time aware model | As a job arrives, first apply VM to super VM, later distance calculated between other jobs and it is in the data center. Depending on the job, assign it to a pod | Scalability framework | Primarily focus on traffic engineering | Graph draw by power consumption | 30% |
| [61] | VM consolidation | CPU | Minimum energy under Performance Constraints | Heuristic algorithms | Performance utilization | Resources are underutilized | Performance comparison | - |
| [62] | VM consolidation | CPU | Minimum power under performance constraints | Resource provisioning framework | Real-time, scalable framework | Unequal allocation of resources | simulation | 26% |
| [63] | VM consolidation | CPU, Memory | Minimize energy consumption | Different QoS levels and a case study | Fewer carbon emissions | Compromise on resources in multiple locations | Average energy consumption, average carbon emission, profit gained, and workload executed | 8% |

**TABLE 1.** *(Continued.)* **Table stylesComparison of energy efficiency techniques in cloud computing.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [64] | DVFS | CPU, Hard disk | Minimize energy consumption | Initially, give the scheduling as a job. Then give the applicable frequency and voltage using DVFS technique | Minimal energy allocation | Jobs are not equally allocated | Simulation | 5-25% |
| [65] | VM Allocation | CPU, Hard disk | Energy saving, memory, storage, minimize power consumption | Comprehensive Bin-Packing and ILP | Maximum energy saving | Mutual power work is ignored | Performance tolerance | 5.90- 41.89% |
| [66] | VMs | CPU | Energy Alert Relocation Algorithm | Energy Alert Relocation Algorithm | Scalability, real-time | Reallocation of dynamic resources | Performance tolerance graph | 22% |
| [67] | VMs | CPU, Memory | Minimize energy consumption | VM Categorization as well as a PM to reduce the usage of PM and implementing VM through parallel implementation interval scheduled a similar PM | Performance utilization | Resources are underutilized | Performance comparison | 30% |
| [68] | VM consolidation | CPU, Hard disk | Energy saving | The UnaCloud Infrastructure | Minimal energy allocation of workloads to servers | Insignificant work on mutual power and performance-aware patterns for multi-dimensional resource distribution | Performance forbearance | 40% |
| [69] | Consolidation, QoS | CPU | Least possible energy consumption | bringing about the desired workload dispersion crosswise | Greater proceeds and fewer carbon | Settlement of resources in multiple | Average energy consumption, | 18% |
| | | | | over servers | emissions | locations | average carbon emission, profit gained, and workload executed | |
| [70] | VMs, SLA | CPU, Hard disk | Energy saving | Power utilization and multi-layered source organization | Real-time and cost-saving under dynamic workload scenarios. | Effective service allocation cannot attain | Simulation using CloudSim toolkit | 30% |
| [71] | QoS, consolidation, virtualization | CPU | Energy and power saving | The QoS necessities come across proficiently | Scalability framework | Mainly focus on traffic engineering | Graph draw by power consumption | - |
| [72] | QoS, Resource utilization | CPU, Memory | Reduces energy consumption | Multi-layered power administration | Real-time, scalable framework | Inadequate allocation of resources | Simulation | 17% |
| [73] | VM, resource utilization | CPU | Energy saving | EAGLE algorithm | Real-time integration of the framework | Resources allocated to VM are not specified | Simulation | 15% |

**TABLE 1.** *(Continued.)* Table stylesComparison of energy efficiency techniques in cloud computing.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [74] | VM placement | CPU | Minimize energy consumption | Power utilization in addition to source organization | Task consolidation with unsystematic, Variations of these algorithms was additionally performed | Promising energy saving capability | Resources are not equally distributed | Simulation |
| [75] | dynamic cloudlet (DCL) | CPU, Memory | Use of green computing in mobile cloud computing | Vigorous power-aware cloud centered mobile cloud computing model (DECM) | Minimal energy allocation of workloads to servers. | Insignificant work on mutual power and performance-aware patterns for multi-dimensional resource distribution. | Performance forbearance | - |
| [76] | DVFS, VM consolidation | CPU, Memory | Minimize energy consumption | Power efficient cloud orchestrator (e-eco), moreover contains cloud contents that choose method over implementation time | Performance utilization | Resources are underutilize | Performance comparison | Up to 25% |
| [77] | Energy-Aware Heterogeneous Cloud Management (EA-HCM) model and Heterogeneous Task Assignment Algorithm (HTA2) | CPU | Minimize energy cost of the mobile heterogeneous embedded systems | Task mitigations by using heterogeneous MES in cloud computing and aimed to reduce the total energy consumption by using cyber-enabled applications to produce optimal task assignment plans. | Better proceeds and fewer carbon emissions. | Settlement of resources in multiple locations | Average energy consumption, average carbon emission, profit gained, and workload executed | -- |
| [78] | Dynamic data allocation | CPU, Memory | data distributions in cloud-based heterogeneous memories | 2DA Algorithm which uses genetic programming to determine data distributions on the cloud-based memories | Response time and cost saving under dynamic workload scenarios | Efficient service allocation cannot attain | Simulation by means of CloudSim toolkit | -- |
| [79] | Heterogeneous computing | CPU, Memory | Task assignment in a heterogeneous cloud | WRM and S2A algorithms | Scalability, real-time | Reallocation of dynamic resources | Performance tolerance graph | -- |

the next section which will help researchers improve energy efficiency for cloud computing.

## IV. OPEN ISSUES AND CHALLENGES

Mostly, cloud computing environment relies on virtualization technologies and that offers the capability to hand over VM among physical nodes. It also leads toward the dynamic consolidation in VMs. In this section, some open issues are identified and that can be addressed at the level of management of vitality procedures of cloud computing.

### A. DYNAMIC VM MIGRATION

Physical properties could fragment keen on a sum of rational wedges known as VM's. Respectively, virtual machines might provide lodgings a single OS that creates a consumer vision of devoted physical resources. This can confirm routine and incompetent remoteness among VMs distribution as separable physical machines [35]. The virtualization layer exists among the OS and tools. Besides these outlines, a VMM proceeds to switch the above source as it should remain incorporated of charter's energy organization.

Altogether these matters need operational consolidation strategies that can reduce power usage deprived of negotiating the performance.

### B. RESOURCE UTILIZATION

Several VMs are enthusiastically taking place on a particular machine to come across conventional applications. Therefore, there is a need to establish several dividers of resources over a particular physical machine towards particular needs of package applications. Various VMs wanting to execute requests will depend on diverse OS situations on a particular physical machine. Furthermore, with dynamic interchanging VMs through physical machines, idle resources are placed in a manner to minimize the energy phase, shut down or intended to function over minimum energy phases (e.g., with DVFS) to save power resources.

### C. RESOURCE SELECTION AND PROVISIONING

Energy efficient source collection shows a significant part of cloud computing. Data centers could distribute diverse stages of enactment to the client node. Therefore, it is important to classify mutual behavior, configurations and infer methodologies that can possibly prime towards further resourceful establishment and subsequent power utilization.

### D. QUALITY OF SERVICE

The quality of service provides overall system performance, in particular, importing cloud computing to applications scheduled on a distributed cloud environment. For cloud computing, it is significant to monitor the QoS globally. In the process of resource and task scheduling within a cloud environment, more efforts should be devoted to handling multiple qualities of service requirements from different users.

### E. CONSOLIDATION OF VMS

There is a connection between power usage, resource utilization, and execution of consolidated jobs. The multiple categories of a virtual machine are consolidated on a physical machine server. The virtual machines cannot be interconnected to each other because of fixed or dynamic workloads. Authors in the survey of [53] disclose the power efficient exchange for consolidation and demonstrate that ideal working facts. Finally, there is a need to plot difficulties in discovering successful answers for consolidation issues.

## V. CONCLUSION

Cloud computing has developed so fast that most data applications depend on it. So, there are many challenges in this area in order to develop different ways to keep cloud computing efficient and meaningful. One of those challenges is efficient power utilization. This is due to the sheer need for cloud computing for almost all applications. These structures not only utilize huge amounts of power, but they also require back ups and cooling stations which they also require power. The power usage diverges proportionally and additionally, there are two irregularities as job denial by the data center and job abortive on servers that are the problems.

The purpose of this review is to explore state-of-the-art for energy and performance administration, power utilization in data centers and proper power distribution. The latest literature (2010-2018) in power and performance management is reviewed and taxonomy is recommended for the categorization of existing procedures grounded on hardware, OS, virtualization, and data-center stages. We present a performance comparison between different energy efficient techniques on the basis of power savings. Also, some open issues and challenges are discussed.

With the cooperation of optimization scheduling and inference techniques, a power consumption can be optimally utilized. An inference module can be embedded to infer future loads of the system, and then, scheduling algorithms are considered to schedule the expected and unpredicted loads, respectively. For future work, the semantically based inference of error detection and recommendation for server and working node logs can overcome the resource underutilization issues. This automatically leads to the more efficient and power saving cloud environment.

## REFERENCES


[1] K. PushpaLatha, R. S. Shaji, and J. P. Jayan, "A cost effective load balancing scheme for better resource utilization in cloud computing," *J. Emerg. Technol. Web Intell.*, vol. 6, no. 3, pp. 280–290, 2014.

[2] F. Owusu and C. Pattinson, "The current state of understanding of the energy efficiency of cloud computing," in *Proc. IEEE 11th Int. Conf. Trust. Secur. Privacy Comput. Commun. (TrustCom)*, Jun. 2012, pp. 1948–1953.

[3] Y. C. Lee and A. Y. Zomaya, "Energy efficient utilization of resources in cloud computing systems," *J. Supercomput.*, vol. 60, no. 2, pp. 268–280, May 2012.

[4] Z. Sanaei, S. Abolfazli, A. Gani, and R. Buyya, "Heterogeneity in mobile cloud computing: Taxonomy and open challenges," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 1, pp. 369–392, 1st Quart., 2014.

[5] J. Baliga, R. W. A. Ayre, K. Hinton, and R. S. Tucker, "Green cloud computing: Balancing energy in processing, storage, and transport," *Proc. IEEE*, vol. 99, no. 1, pp. 149–167, Jan. 2011.

[6] S.-Y. Jing, S. Ali, K. She, and Y. Zhong, "State-of-the-art research study for green cloud computing," *J. Supercomput.*, vol. 65, no. 1, pp. 445–468, 2013.

[7] H. Chen, X. Zhu, H. Guo, J. Zhu, X. Qin, and J. Wu, "Towards energy-efficient scheduling for real-time tasks under uncertain cloud computing environment," *J. Syst. Softw.*, vol. 99, pp. 20–35, Jan. 2015.

[8] A. Banerjee, P. Agrawal, and N. C. S. N. Iyengar, "Energy efficiency model for cloud computing," *Int. J. Energy, Inf. Commun.*, vol. 4, no. 6, pp. 29–42, Dec. 2013.

[9] S. U. Kliazovich, D. Bouvry, P. Audzevich, and Y. Khan, "GreenCloud: A packet-level simulator of energy-aware cloud computing data centers," in *Proc. Globe Telecommun. Conf. (GLOBECOM)*, 2012, pp. 1–5.

[10] D. Kliazovich, P. Bouvry, and S. U. Khan, "DENS: Data center energy-efficient network-aware scheduling," *Cluster Comput.*, vol. 16, no. 1, pp. 65–75, Sep. 2011.

[11] I. S. Moreno, R. Yang, J. Xu, and T. Wo, "Improved energy-efficiency in cloud datacenters with interference-aware virtual machine placement," in *Proc. IEEE 11th Int. Symp. Auton. Decentralized Syst.*, Mar. 2013, pp. 1–8.

[12] R. Tucker, K. Hinton, and R. Ayre, "Energy-efficiency in cloud computing and optical networking," in *Eur. Conf. Exhib. Opt. Commun. OSA Tech. Dig. (Opt. Soc. Amer.)*, Sep. 2012, pp. 1–32, paper. Th.1.

[13] C. Fiandri, D. Kliazovich, P. Bouvry, and A. Zomaya, "Performance and energy efficiency metrics for communication systems of cloud computing data centers," *IEEE Trans. Cloud Comput.*, vol. 99, p. 14, 2015.

[14] U. Wajid, B. Pernici, and G. Francis, "Energy efficient and $CO_2$ aware cloud computing: Requirements and case study," in *Proc. IEEE Int. Conf. Syst., Man, Cybern. (SMC)*, Oct. 2013, pp. 121–126.

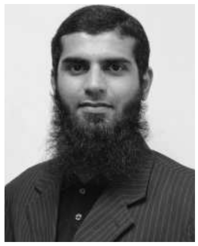
[15] M. Stillwell, D. Schanzenbach, F. Vivien, and H. Casanova, "Resource allocation algorithms for virtualized service hosting platforms," *J. Parallel Distrib. Comput.*, vol. 70, no. 9, pp. 962–974, 2010.

[16] C. Aschberger and F. Halbrainer, "Energy efficiency in cloud computing," *HCTL Open Int. J. Technol. Innov. Res.*, vol. 7, pp. 1–16, Jan. 2013.
[17] S. Goyal, S. Bawa, and B. Singh, "Experimental comparison of three scheduling algorithms for energy efficiency in cloud computing," in *Proc. IEEE Int. Conf. Cloud Comput. Emerg. Markets (CCEM)*, Oct. 2014, pp. 1–6.
[18] H. Goudarzi and M. Pedram, "Energy-efficient virtual machine replication and placement in a cloud computing system," in *Proc. IEEE 6th Int. Conf. Cloud Comput.*, Jun. 2012, pp. 750–757.
[19] Y. Sharma, B. Javadi, and W. Si, "On the reliability and energy efficiency in cloud computing," *Parallel Distrib. Comput.*, vol. 27, p. 111, 2015.
[20] M. Lin, A. Wierman, L. L. H. Andrew, and E. Thereska, "Dynamic right-sizing for power-proportional data centers," *IEEE/ACM Trans. Netw.*, vol. 21, no. 5, pp. 1378–1391, Oct. 2013.
[21] H. Esmaeilzadeh, T. Cao, Y. Xi, S. M. Blackburn, and K. S. McKinley, "Looking back on the language and hardware revolutions: Measured power, performance, and scaling," *ACM SIGPLAN Notices*, vol. 47, no. 4, pp. 319–332, 2012.
[22] L. Y. Xiao, Z. Wang, R. Wang, and H. N. Wang, "Architecture and key technologies of cloud computing," *Adv. Mater. Res.*, vols. 756–759, pp. 1953–1956, Sep. 2013.
[23] "Energy efficiency in operating systems outline," in *Arbeitsbereich Wissenschaftliches Rechnen Fachbereich Informatik*. 2014, pp. 119–126. [Online]. Available: https://wr.informatik.uni-hamburg.de/_media/teaching/wintersemester_2014_2015/eep-1415-broemstrup-operating-systems-notes.pdf
[24] A. Khosravi, S. K. Garg, and R. Buyya, "Energy and carbon-efficient placement of virtual machines in distributed cloud data centers," in *Proc. Eur. Conf. Parallel Process.*, 2013, pp. 317–328.
[25] K. Djemame *et al.*, "Energy efficiency embedded service lifecycle: Towards an energy efficient cloud computing architecture," in *Proc. CEUR Workshop*, vol. 1203, 2014, p. 1–6.
[26] K. H. Kim and R. Buyya, "Power-aware provisioning of cloud resources for real-time services," *J. Supercomput.*, vol. 65, p. 16, Dec. 2011.
[27] G. Luigi *et al.*, "An overview of energy efficiency techniques in cluster computing systems," *Cluster Comput.*, vol. 16, no. 1, pp. 3–15, 2013.
[28] M. Barbulescu *et al.*, "Energy efficiency in cloud computing and distributed systems," Sep. 2013, pp. 1–5.
[29] T. J. Nirubah, M. Rose, and R. John, "A survey of the impact of task scheduling algorithms on energy-efficiency in cloud computing," *Int. J. Eng. Res. Technol.*, vol. 3, no. 1, pp. 1287–1291, 2014.
[30] Y. Cui, X. Ma, H. Wang, I. Stojmenovic, and J. Liu, "A survey of energy efficient wireless transmission and modeling in mobile cloud computing," *Mobile Netw. Appl.*, vol. 18, no. 1, pp. 148–155, 2013.
[31] H. T. Dinh, C. Lee, D. Niyato, and P. Wang, "A survey of mobile cloud computing: Architecture, applications, and approaches," *Wireless Commun. Mobile Comput.*, vol. 13, no. 18, pp. 1587–1611, 2013.
[32] T. Mathew, K. C. Sekaran, and J. Jose, "Study and analysis of various task scheduling algorithms in the cloud computing environment," in *Proc. Int. Conf. Adv. Comput., Commun. Inform. (ICACCI)*, Sep. 2014, pp. 658–664.
[33] L. Luo, W. Wu, D. Di, F. Zhang, Y. Yan, and Y. Mao, "A resource scheduling algorithm of cloud computing based on energy efficient optimization methods," in *Proc. Int. Green Comput. Conf. (IGCC)*, Jun. 2012, pp. 1–5.
[34] A. Gandhi, M. Harchol-Balter, R. Das, and C. Lefurgy, "Optimal power allocation in server farms," in *Proc. 11th Int. Jt. Conf. Meas. Modeling Comput. Syst. (SIGMETRICS)*, 2009, pp. 157–168.
[35] J. D. Pagare and N. A. Koli, Energy-efficient cloud computing: A vision, introduction, and open challenges, *Int. J. Comput. Sci. Netw.*, vol. 2, no. 2, pp. 96–102, 2013.
[36] X. Ma, Y. Cui, and I. Stojmenovic, "Energy efficiency on location based applications in mobile cloud computing: A survey," *Procedia Comput. Sci.*, vol. 10, pp. 577–584, 2012.
[37] A. Uchechukwu, K. Li, and Y. Shen, "Improving cloud computing energy efficiency," in *Proc. IEEE Asia Pacific Cloud Comput. Congr. (APCloudCC)*, Nov. 2012, pp. 53–58.
[38] X. Cai and C. Wang, "Research on energy efficiency evaluation in the cloud," vol. 15, pp. 441–445, 2015.
[39] Q. Zhang, L. Cheng, and R. Boutaba, "Cloud computing: State-of-the-art and research challenges," *J. Internet Services Appl.*, vol. 1, no. 1, pp. 7–18, Apr. 2010.
[40] J. W. Smith, "Investigating performance and energy efficiency on a private cloud," Doctoral dissertation, Univ. St Andrews, St Andrews, U.K., 2014.
[41] D. Meisner, B. T. Gold, and T. F. Wenisch, "The PowerNap server architecture," *ACM Trans. Comput. Syst.*, vol. 29, no. 1, Feb. 2011, Art. no. 3.
[42] J.-A. Hong, S. Seo, N. Kim, and B.-D. Lee, "A study of secure data transmissions in mobile cloud computing from the energy consumption side," in *Proc. Int. Conf. Inf. Netw. (ICOIN)*, Jan. 2013, pp. 250–255.
[43] S. Abolfazli, Z. Sanaei, M. Alizadeh, A. Gani, and F. Xia, "An experimental analysis on cloud-based mobile augmentation in mobile cloud computing," *IEEE Trans. Consum. Electron.*, vol. 60, no. 1, pp. 146–154, Feb. 2014.
[44] J. Li, J. Peng, and W. Zhang, "A scheduling algorithm for private clouds," *J. Converg. Inf. Technol.*, vol. 6, no. 7, p. 19, Jul. 2011.
[45] Z. Zhou, Z.-G. Hu, T. Song, and J.-Y. Yu, "A novel virtual machine deployment algorithm with energy efficiency in cloud computing," *J. Central South Univ.*, vol. 22, no. 3, pp. 974–983, 2015.
[46] W. Deng, F. Liu, H. Jin, B. Li, and D. Li, "Harnessing renewable energy in cloud datacenters: Opportunities and challenges," *IEEE Netw.*, vol. 28, no. 1, pp. 48–55, Apr. 2012.
[47] J. Subirats and J. Guitart, "Assessing and forecasting energy efficiency on Cloud computing platforms," *Future Gener. Comput. Syst.*, vol. 45, pp. 70–94, Apr. 2015.
[48] R. Tucker, "Towards an energy-efficient Internet," in *Light. Energy Environ. OSA Tech. Dig. (Opt. Soc. Amer.*, 2014, paper EF3A.1.
[49] S. Kumar, S. Versteeg, and R. Buyya, "A framework for ranking of cloud computing services," *Future Gener. Comput. Syst.*, vol. 29, no. 4, pp. 1012–1023, 2013.
[50] S. Parsa and R. Entezari-Maleki, "RASA: A new task scheduling algorithm in grid environment," *Int. J. Digit. Content Technol. Appl.*, vol. 3, no. 4, pp. 91–99, 2010.
[51] G. Procaccianti, P. Lago, and S. Bevini, "A systematic literature review on energy efficiency in cloud software architectures," *Sustain. Comput., Inform. Syst.*, vol. 7, pp. 2–10, Sep. 2015.
[52] S. K. Garg, C. S. Yeo, A. Anandasivam, and R. Buyya, "Environment-conscious scheduling of HPC applications on distributed Cloud-oriented data centers," *J. Parallel Distrib. Comput.*, vol. 71, no. 6, pp. 732–749, Jun. 2011.
[53] S. Srikantaiah, A. Kansal, and F. Zhao, "Energy aware consolidation for cloud computing," in *Proc. 2nd Int. Conf. Power-Aware Comput. Syst. (PACS)*, vol. 12. 2010, pp. 1–5.
[54] W. Ahmad *et al.*, "A survey on virtual machine migration and server consolidation frameworks for cloud data centers," *J. Netw. Comput. Appl.*, vol. 52, pp. 11–25, 2015.
[55] Z. Sanaei, S. Abolfazli, A. Gani, and R. H. Khokhar, "Tripod of requirements in horizontal heterogeneous mobile cloud computing," in *Proc. WSEAS CISCO*, Singapore, 2012.
[56] S. V. Kiran, J. Thriveni, S. Raghuram, and K. R. Venugopal, "Cloud resource reduction evaluation by video caching and streaming in LAN environment," *CSI Trans. ICT*, vol. 5, no. 4, pp. 387–395, 2017.
[57] R. Buyya, A. Beloglazov, and J. Abawajy, "Energy-efficient management of data center resources for cloud computing: A vision, architectural elements, and open challenges," in *Proc. Int. Conf. Parallel Distrib. Process. Tech. Appl. (PDPTA)*, Las Vegas, CA, USA, 2010, pp. 1–12.
[58] S. Srivastava, P. M. Khan, and R. Beg, "Energy efficient approach for cloud to improve environmental effect," *Int. J. Softw. Eng. Res. Pract.*, vol. 4, no. 1, pp. 14–19, 2014.
[59] I. M. Moreno-Vozmediano, R. S. Montero, and R. S. Llorente, "Key challenges in cloud computing: Enabling the future Internet of services," *IEEE Internet Comput.*, vol. 17, no. 4, pp. 18–25, Jul./Aug. 2013.
[60] L. Wang *et al.*, "GreenDCN: A general framework for achieving energy efficiency in data center networks," *IEEE J. Sel. Areas Commun.*, vol. 32, no. 1, pp. 4–15, Jan. 2014.
[61] M. Stillwell, D. Schanzenbach, F. Vivien, and H. Casanova, "Resource allocation using virtual clusters," in *Proc. IEEE/ACM Int. Symp. Clust. Comput. Grid (CCGRID)*, vol. 17, 2010, pp. 18–25.
[62] Y. Liu, S. C. Draper, and N. S. Kim, "Queuing theoretic analysis of power-performance tradeoff in power-efficient computing," in *Proc. CISS*, Mar. 2013, pp. 1–6.
[63] D. Gmach, J. Rolia, L. Cherkasova, and A. Kemper, "Resource pool management: Reactive versus proactive or let's be friends," *Comput. Netw.*, vol. 53, no. 17, pp. 2905–2922, 2009.
[64] C.-M. Wu, R.-S. Chang, and H.-Y. Chan, "A green energy-efficient scheduling algorithm using the DVFS technique for cloud datacenters," *Future Generat. Comput. Syst.*, vol. 37, pp. 141–147, Jul. 2014.
[65] C. Ghribi, M. Hadji, and D. Zeghlache, "Energy efficient VM scheduling for cloud data centers: Exact allocation and migration algorithms," in *Proc. 13th IEEE/ACM Int. Symp. Clust. Cloud, Grid Comput. (CCGrid)*, May 2013, pp. 671–678.

[66] A. Beloglazov and R. Buyya, "Energy efficient allocation of virtual machines in cloud data centers," in *Proc. 10th IEEE/ACM Int. Conf. Clust. Cloud, Grid Comput. (CCGrid)*, May 2010, pp. 577–578.
[67] C. O. Diaz, H. Castro, M. Villamizar, J. E. Pecero, and P. Bouvry, "Energy-aware VM Allocation on an opportunistic cloud infrastructure," in *Proc. 13th IEEE/ACM Int. Symp. Clust. Cloud, Grid Comput. (CCGrid)*, May 2013, pp. 663–670.
[68] S. Kikuchi and Y. Matsumoto, "Impact of live migration on multi-tier application performance in clouds," in *Proc. IEEE 5th Int. Conf. Cloud Comput. (CLOUD)*, Jun. 2012, pp. 261–268.
[69] A. Beloglazov, J. Abawajy, and R. Buyya, "Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing," *Future Generat. Comput. Syst.*, vol. 28, no. 5, pp. 755–768, May 2012.
[70] J. Goiri *et al.*, "Energy-efficient and multifaceted resource management for profit-driven virtualized data centers," *Future Generat. Comput. Syst.*, vol. 28, no. 5, pp. 718–731, 2012.
[71] B. Dougherty, J. White, and D. C. Schmidt, "Model-driven auto-scaling of green cloud computing infrastructure," *Future Generat. Comput. Syst.*, vol. 28, no. 2, pp. 371–378, 2012.
[72] C.-H. Hsu, K. D. Slagter, S.-C. Chen, and Y.-C. Chung, "Optimizing energy consumption with task consolidation in clouds," *Inf. Sci.*, vol. 258, pp. 452–462, Feb. 2014.
[73] X. Li, Z. Qian, S. Lu, and J. Wu, "Energy efficient virtual machine placement algorithm with balanced and improved resource utilization in a data center," *Math. Comput. Model.*, vol. 58, nos. 5–6, pp. 1222–1235, 2013.
[74] W. Fang, X. Liang, S. Li, L. Chiaraviglio, and N. Xiong, "VMPlanner: Optimizing virtual machine placement and traffic flow routing to reduce network power costs in cloud data centers," *Comput. Netw.*, vol. 57, no. 1, pp. 179–196, 2013.
[75] K. Gai, M. Qiu, H. Zhao, L. Tao, and Z. Zong, "Dynamic energy-aware cloudlet-based mobile cloud computing model for green computing," *J. Netw. Comput. Appl.*, vol. 59, pp. 46–54, Jan. 2016.
[76] F. D. Rossi, M. G. Xavier, C. A. F. De Rose, R. N. Calheiros, and R. Buyya, "E-eco: Performance-aware energy-efficient cloud data center orchestration," *J. Netw. Comput. Appl.*, vol. 78, pp. 83–96, Jan. 2017.
[77] K. Gai, M. Qiu, and H. Zhao, "Energy-aware task assignment for mobile cyber-enabled applications in heterogeneous cloud computing," *J. Parallel Distrib. Comput.*, vol. 111, pp. 126–135, Jan. 2018.
[78] K. Gai, M. Qiu, and H. Zhao, "Cost-aware multimedia data allocation for heterogeneous memory using genetic algorithm in cloud computing," *IEEE Trans. Cloud Comput.*, to be published.
[79] K. K. Gai, M. K. Qiu, H. Zhao, and X. T. Sun, "Resource management in sustainable cyber-physical systems using heterogeneous cloud computing," *IEEE Trans. Sustain. Comput.*, to be published.

**QAISAR SHAHEEN** received the M.Sc. degree (CS) from the Federal Urdu University of Arts, Sciences and Technology Islamabad, Pakistan, in 2009, and the M.S. degree (CS) from the University of Lahore, Pakistan, in 2013. He is currently pursuing the Ph.D. degree from Superior University, Lahore, Pakistan. His research interests include cloud computing, wireless sensor networks, integration of wireless Sensor network and cloud computing, and Internet of Things.

**MUHAMMAD SHIRAZ** received the master's degree in computer science from Allama Iqbal Open University, Islamabad, Pakistan, in 2007. He is currently pursuing the Ph.D. degree under the Commonwealth Scholarship Program with the Faculty of Computer and Information Technology, University of Malaya, Malaysia. He is currently an Assistant Professor with the Department of Computer Science, Federal Urdu University of Arts, Sciences and Technology, Islamabad, Pakistan. He is also an Active Researcher with the Mobile Cloud Computing Research Group, FCSIT. His areas of interest include distributed applications design for ubiquitous networks, distributed systems, lightweight applications, smart client applications and optimization strategies, and mobile cloud computing. He is a reviewer of the *Journal of Network and Computer Applications*.



**SULEMAN KHAN** received the M.S. degree in distributed systems from the COMSATS Institute of Information Technology, Abbottabad, Pakistan, in 2011, the M.B.A degree (HRD) from the Institute of Management of Sciences, Hayatabad, Pakistan, in 2007, the M.Sc. degree in computer science from the University of Peshawar, Pakistan, in 2006, and the Ph.D. degree (Hons.) from the Faculty of Computer Science and Information Technology, University of Malaya, Malaysia in 2017. He is currently a Faculty Member with the School of Information Technology, Monash University Malaysia. He has published over 40 High Impact Research articles in reputed international journals and conferences. His research areas include but are not limited to network security, network forensics, software defined networks, Internet of Things, cloud computing, and vehicular communication.

**RABIA MAJEED** received the B.S. degree (CS) from Bahauddin Zakariya University Multan, Pakistan, in 2010, the M.S. degree (CS) from COMSATS Institute of Information Technology, Islamabad, Pakistan, in 2017. She is currently a Research Associate with the COMSATS Institute of Information Technology Islamabad, Pakistan. Her research interest includes semantic Web, ontologies, and cloud computing.

**MOHSEN GUIZANI** (S'85–M'89–SM'99–F'09) received the B.S. (Hons.) and M.S. degrees in electrical engineering and the M.S. and Ph.D. degrees in computer engineering from Syracuse University, Syracuse, NY, USA, in 1984, 1986, 1987, and 1990, respectively. He is currently a Professor and the ECE Department Chair with the University of Idaho, USA. He served as the Associate Vice President for Graduate Studies, Qatar University, the Chair of the Computer Science Department, Western Michigan University, and the Chair of the Computer Science Department, University of West Florida. He also served in academic positions with the University of Missouri-Kansas City, University of Colorado-Boulder, Syracuse University, and Kuwait University. He has authored nine books and over 450 publications in refereed journals and conferences. His research interests include wireless communications and mobile computing, computer networks, mobile cloud computing, security, and smart grid. He is a Senior Member of ACM. He was a recipient of teaching awards multiple times from different institutions as well as best research awards from three institutions. He also served as a member, the chair, and the general chair of a number of international conferences. He was the Chair of the IEEE Communications Society Wireless Technical Committee and the Chair of the TAOS Technical Committee. He currently serves on the editorial boards of several international technical journals and is the Founder and the Editor-in-Chief of *Wireless Communications and Mobile Computing* (Wiley). He guest edited a number of special issues in the IEEE journals and magazines. He served as the IEEE Computer Society Distinguished Speaker from 2003 to 2005.

**NAWSHER KHAN** received the bachelor's degree in computer science from the University of Peshawar, Pakistan, in 1998, the master's degree in computer science from Hazara University, Pakistan, in 2005, and the Ph.D. degree from Universiti Malaysia Pahang, Malaysia, in 2013. He was a Post-Doctoral Research Fellow with the University of Malaya, Kuala Lumpur, Malaysia, in 2014. Since 1999, he has been with various educational institutions. In 2005, he was appointed in the National Database and Registration Authority under the Interior Ministry of Pakistan. In 2008, he has worked in the National Highways Authority. He is currently serving as an Associate Professor/Head of Research with King Khalid University, Abha, Saudi Arabia. He is currently on leave from Abdul Wali Khan University Mardan, Pakistan. In addition, he has published over 50 articles in various international journals and conference proceedings. His areas of interest include big data, cloud computing, data management, distributed system, scheduling, and replication and sensor network.

**ALI M. ASEERE** received the Ph.D. degree in computer science from the University of Southampton, U.K., in 2012. He is currently the Dean of the Collage of Computer Science, King Khalid University, Abha, Saudi Arabia. He has published many research papers in refereed International Journals/Proceedings/Books. His research areas are intelligent and multi-agent systems, agent-based models, agent mining, and image processing.